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On the determination of absolute internal conversion coefficients by the comparison of conversion lines and photolines

An application to the 662 keV transition in the decay of Cs^{137}

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With 3 figures in the text

Introduction

An internal conversion coefficient ε is defined as the ratio between the numbers of conversion electrons and accompanying gamma rays per unit time as observed in a nuclear transition between excited states. It is known that ε depends strongly upon parameters such as the nuclear charge, the atomic shell from which the conversion electrons are expelled, the energy and multipole character of the electromagnetic radiation and the nuclear size. Because of its sensitivity to such important quantities ε has been and still is the object of a considerable theoretical and experimental interest. The theoretical calculations are involved and it is only recently that the influence on ε from the nuclear size has been taken into account (Sliv and Band 1956, Rose 1957).

Experimentally, the problem of finding ε has been the interest of many investigations and several methods have been worked out. The most useful of these seem to be

(1) a comparison between the intensities of the gamma ray and the corresponding X-ray;
(2) a comparison between the conversion electron intensity of the actual transition with the total feeding to this transition;
(3) an observation of electron-electron or electron-gamma coincidences;
(4) a comparison of conversion lines and photolines ("relative" or "absolute" ε-values can be obtained).

The first method is more or less limited to those cases where only one gamma ray is emitted (Bergström *et al.* 1953). The second one has been used with fair accuracy (Waggoner 1950, Wapstra 1954, Yoshizawa 1958) but it is subject to severe limitations in that it can be used only with the most simple beta-decays. Both these methods require a complete knowledge of the decay schemes for the deduction of ε from the measured data. The third method is more general; only the coincidence probability between two transitions must be known. Here the shortcomings are that often the coincidence coupling rate is not known and that the coincidence counting rate may become inconveniently low with a consequent loss of accuracy (Gerholm 1956). For a comprehensive review and a more detailed description of methods for experimental determinations of internal conversion coefficients the reader is referred to the article in *Handbuch der Physik* by Alburger 1957.

The fourth method requires in its *relative* sense that one transition in the actual decay be accurately known as to its multipolarity character (Novakov *et al.* 1958). In its *absolute* sense, however, this limitation is removed and the method permits of a general determination of ε in an unknown or/and complex decay (Stockendal and Hultberg 1959); the only requirement left is that it must be possible to identify the conversion line and the photoline belonging to the same transition. This condition can almost always be fulfilled.

There are, however, some difficulties that explain the relatively infrequent use of this principally very attractive method. The most prominent of these are:

(1) fairly strong radioactive sources, often of the order of 10 mC or more, are required;
(2) accurate information about the variation of the photoelectric cross-section with respect to the photon energy and to the angular dependence is necessary.

The *absolute* determination of ε also requires

(3) a radioactive source which can be used for both internal and external conversion (it must be thin and very intense at the same time); alternatively, two sources of known relative strengths can be employed;
(4) an accurate knowledge of the converter thickness which should have a good uniformity and be thin enough to permit of a high resolution for the application to complex decays.

The necessary information concerning the photoelectric angular distribution may alternatively be had by calibrating a special source-converter arrangement with transitions of known ε-values. There are, however, practical difficulties in finding isotopes of suitable energies and half-lives and in the necessity of repeating the calibration procedure if the set-up geometry is changed. More seriously, however, the resulting ε-values will be dependent on the information about a number of other decay schemes. If the determination of ε is to be self-consistent the second of the above requirements must necessarily be fulfilled.

It is the object of the present paper to report a study of the extension of the fourth method to the experimental determination of *absolute* ε-values. As an application the ε of the 662 keV transition in Ba^{137} was measured. The instrument used was a large double-focusing beta-ray spectrometer.

The possibility of obtaining absolute ε-values in this way was pointed out by Murray 1954, who made an application in a helical spectrometer (Murray 1955). However, because of large uncertainties in some of the parameters (partly due to lack of accurate knowledge of the angular dependence) the method could not be used with sufficient accuracy and, to our knowledge, a close inspection of its powers has not yet been made. The source-converter geometry problem in a helical spectrometer and its connection with the theoretical angular distribution was also studied by Thomas 1952.

The analysis of photolines recorded in a double-focusing spectrometer

The following definitions will be used:

ε	internal conversion coefficient $= \alpha$ or β
I_β	number of conversion electrons emitted per disintegration and per unit solid angle
I_γ	number of gamma rays emitted per disintegration and per unit solid angle
A_β	intensity of conversion electrons
A_γ	intensity of photoelectrons
$J(\theta)$	angular part of photoelectric cross-section per unit solid angle
τ	tabulated value of photoelectric cross-section for an *atomic shell* (barns/atom)
k_β, k_γ	source strengths (disintegrations per second)
k	relative source strength $= k_\gamma/k_\beta$
d	converter thickness (mg/cm^2)
b	dimension factor (atom $\times$ cm^2/(barns $\times$ mg)) $= 6.025 \cdot 10^{-4}/M$[1]
c_β, c_γ	spectrometer transmission factors

Fig. 1 depicts schematically the experimental arrangement in the spectrometer with a point source at Q, emitting gamma rays isotropically. Let us choose a surface element dS at R on the converter. dS subtends a solid angle $d\Omega_\gamma = (dS \cdot \cos\vartheta)/r^2$ at Q if the total solid angle is defined as 4π. The number of gamma rays striking dS per sec is $I_\gamma k_\gamma d\Omega_\gamma$; the absorption of these quanta is proportional to the path length $d/\cos\vartheta$ in the converter and to the differential photoelectric cross-section per unit solid angle $N \cdot J(\theta)$, for unpolarized gamma radiation, where N is an angle-

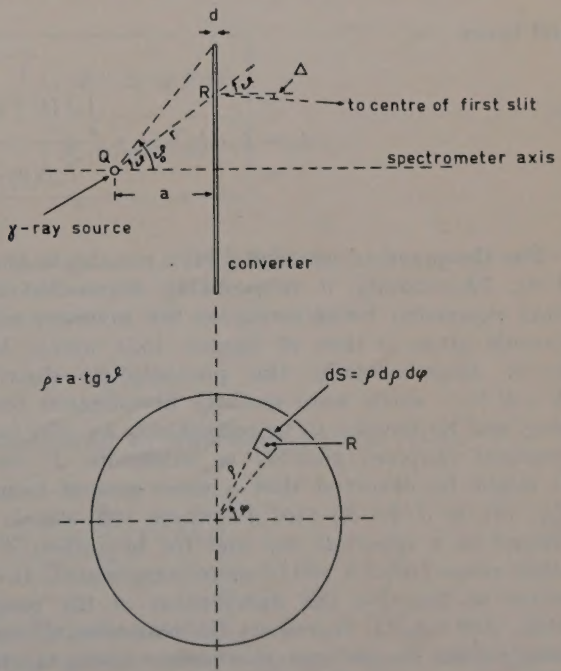

Fig. 1. Schematic source–converter assembly used in the double-focusing spectrometer.

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[1] M = atomic weight of the radiating atoms.

independent factor. For a specific transition the photoelectric intensity through the entrance baffle will be given by

$$I_\gamma k_\gamma b N \Omega_e \int_C J(\vartheta + \Delta) \frac{d}{\cos\vartheta} d\Omega_\gamma = A_\gamma, \tag{1}$$

where $\theta = \vartheta + \Delta$ and where C implies an integration over the converter. Ω_e denotes the solid angle which the entrance baffle subtends at R. The geometry is such that Ω_e is small and remains practically constant over the whole converter surface. Δ it the (small) angle between the normal at R and the direction through the baffle centre. Introducing polar coordinates in the converter plane according to Fig. 1 with $\cos\vartheta = a/r$, $\mathrm{tg}\vartheta = \varrho/a$ and $dS = \varrho\, d\varrho\, d\varphi = r^2\, \mathrm{tg}\vartheta\, d\vartheta\, d\varphi$ gives (after an integration over φ)

$$A_\gamma = I_\gamma d\, k_\gamma b N\, 2\pi\, \Omega_e \int_0^{\vartheta_0} J(\vartheta + \Delta)\, \mathrm{tg}\vartheta\, d\vartheta. \tag{2}$$

According to the definition of the total absorption cross-section τ (for a specific shell) one can write, for a specific shell,

$$\tau = N\, 2\pi \int_0^{\pi} J(\theta) \sin\theta\, d\theta, \tag{3}$$

and hence

$$A_\gamma = I_\gamma d\, k_\gamma b\, \Omega_e \tau \frac{\int_0^{\vartheta_0} J(\vartheta + \Delta)\, \mathrm{tg}\vartheta\, \mathrm{d}\vartheta}{\int_0^{\pi} J(\theta) \sin\theta\, d\theta}. \tag{4}$$

For the practical use of Eq. (4) it remains to obtain a substitute for $J(\vartheta + \Delta)$ and $J(\theta)$. *Theoretically*, it is probably impossible to arrive at a closed and practical expression for J owing to the involved mathematical formalism; the only formula given is that of Sauter 1931 which, however, is strictly true *only for* $Z = 0$. *Experimentally*, the photoelectric distributions J_e for the K, L, and $M + N + \cdots$ shells were recently investigated for three quantum energies (Hultberg and Sujkowski, to be published). As will be made plausible below it is for practical purposes possible to substitute J_e for $J(\vartheta + \Delta)$ and $J(\theta)$ in Eq. (4). It might be observed that a more general form of the nominator integrand of Eq. (4) is $J(\vartheta + \Delta)\, f(\vartheta)\, d\vartheta$ where $f(\vartheta)$ stands for $\sin\vartheta$ when the converter is formed as a spherical cap and for $\mathrm{tg}\vartheta$ when it is shaped as a circular disc. For other cases $f(\vartheta)\, d\vartheta$ will be more complicated. It should thus be clear that $f(\vartheta)\, d\vartheta$ serves to describe the distribution of the gamma radiation upon the radiator while $J(\vartheta + \Delta)\, \Omega_e$ represents the photoelectric emission through the baffle opening from a point on the converter surface seeing the baffle centre under an angle $\vartheta + \Delta$ with respect to the direction of incidence of the gamma rays.

As no satisfactory formula for J has been given the substitution of the *experimental* distributions J_e for $J(\vartheta+\Delta)$ and $J(\theta)$ was tried. That such a procedure is possible with sufficient accuracy may, however, not be clear immediately because J_e results from a measurement of J with an experimental arrangement which introduces "distortions" in J on account of the impossibility of realizing an infinitely high angular resolution and an infinitely thin converter (Hultberg 1955). A more detailed investigation of the problem of inferring J from J_e has been started but no quantitative results will be given here. Preliminarily, however, it might be remarked that while the geometrical diffuseness is large at $\theta=0^\circ$ and 180° it rapidly decreases as θ tends towards 90°. The effect of the difference between J and J_e (which is appreciable only at small θ:s) is, however, greatly reduced by the multiplication with the sine or tangent functions. Regarding multiple scattering of the photoelectrons it might be observed that the same converter can be used in the study of J_e and in the ordinary measurements of photolines for the evaluation of gamma-ray intensities. It should then be possible to obtain a J_e with the correct dependence upon the scattering. These and related questions will be more fully discussed by Hultberg, to be published.

There are consequently reasons to believe that even the substitution of an *uncorrected experimental* distribution J_e into Eq. (4) will introduce an error that is in most cases negligible compared with uncertainties in the determination of other quantities involved in the deduction of gamma-ray intensities.

Substituting J_e for J into Eq. (4) and rearranging the factors we finally get

$$A_\gamma = I_\gamma\, \tau\, f\, d\, k_\gamma\, b\, c_\gamma \tag{5}$$

where

$$\boxed{f = \frac{\int_0^{\vartheta_0} J_e(\vartheta+\Delta)\,\mathrm{tg}\,\vartheta\, d\vartheta}{\int_0^{\pi} J_e(\theta)\sin\theta\, d\theta}.} \tag{6}$$

For convenience, Ω_e has been changed to c_γ which represents a constant, mainly depending upon the baffle adjustments in the spectrometer.

The intensity A_β of a recorded conversion line can be written

$$A_\beta = I_\beta\, k_\beta\, c_\beta. \tag{7}$$

The conversion coefficient ε is obtained by combining (5) and (7) as

$$\boxed{\varepsilon = \frac{I_\beta}{I_\gamma} = \frac{A_\beta}{A_\gamma}\,\tau\, f\, d\, k\, b}, \tag{8}$$

where $c_\beta = c_\gamma$ is assumed (fixed baffle adjustments).

The functional dependence of the nominator integral in the factor f can be tested by recording photolines A_γ with all parameters of Eq. (5) being kept constant except the upper limit ϑ_0 of the integral. This can be achieved by moving the gamma-ray source on the normal through the converter centre and measuring A_γ for different source-converter distances. The experiment was carried out for 12–14 ϑ_0-values in the interval $8° \leqslant \vartheta_0 \leqslant 78°$, for each of the three standard gamma-ray energies 412, 662 and 1332 keV (using 2×2 mm cylindrical sources). It was found that Eq. (5) represents A_γ correctly on a relative scale. This experience lends strong support to the above assumption of the possibility of using uncorrected experimental angular distributions in Eq. (5).

It the derivation of Eq. (5) it has been understood that the gamma-ray source has no geometrical extension, i.e. that it forms a mathematical point. Although Eq. (5) is strictly true only in such a case it would seem reasonable to hope that no serious deviations from the idealized case occur as long as the extension of the source is small compared with that of the converter. A test was made by repeating the above-mentioned experiments with a gamma-ray source, the linear dimensions of which being three times those of the source used above. Within the experimental accuracy no significant difference between the two cases was observed. A rough estimate of a possible effect of this character was in agreement with this result.

For the practical use of Eqs. (5) and (8) it remains to evaluate the factor f according to formula (6). For this and for other reasons as well the longitudinal angular photoelectric distributions J_e were recently measured with a 2.19 mg/cm^2 U radiator. At every setting of the angle θ the K, L, and $M+N+\ldots$ photolines were carefully recorded (Hultberg and Sujkowski, to be published) for the gamma-ray energies 412, 662 and 1332 keV. From the complete angular distributions the factor f could be determined and the relative absorption for the K, L, and $M+N+\ldots$ shells in the uranium atom could be calculated. As a result it might be mentioned that the $\frac{5}{4} = 1.25$ "thumb rule" for the $(K+L+M+\ldots)/K$ ratio in external conversion was well verified. Values around 1.27 were obtained for U in the energy interval covered by the above-mentioned energies. Details of this work will appear later in this journal. For the sake of interest it might be mentioned here that, in order to obtain τ_a from τ_K (a denotes the whole atom), G. White substitutes theoretical $(K+L+M)/K$-ratios for τ_a/τ_K, neglecting contributions from higher shells. For $Z=92$, these ratios are given as 1.167 for $h\nu < 340$ keV and as 1.138 for $h\nu > 340$ keV. A comparison with our experimental results indicates that the theoretical factors are too small.

It seems to be convenient to treat τf as a new photoelectric cross-section, applicable to a special experimental arrangement. τ_K-values can be obtained from the National Bureau of Standards Circular 583 (G. White 1957) by dividing the tabulated $K+L+M$ cross-sections by the appropriate (theoretical) factors $(K+L+M)/K$ in Table 5 of the circular. For practical use the τ_K so obtained is plotted versus energy in a log-log diagram (see Fig. 5 in the following paper by Stockendal and Hultberg 1958) and, for the three energies quoted above, the "corrected" cross-section $\tau_K f$ is entered in the diagram. However, it is difficult to draw a curve correctly through only three points. The situation would be much improved were it possible to obtain estimates of f for very high and very low energies. Fortunately, this is, in fact, the case, as will be shown below.

An inspection of the character of the angular distributions as the quantum energy increases shows that $f \rightarrow 1$ at *high energies* because then the distributions will fall off very rapidly as θ increases, making the integrals in Eq. (6) almost equal. This is demonstrated experimentally by the angular distribution at 2.6 MeV as measured for Pb by Latyshev 1947. Here f will be near 1.[1] The difference between f(Pb) and f(U) will be negligible at high energies. Thus at 4–5 MeV f can safely be put = 1.

At *low energies* the direction of maximum photoelectric emission tends towards $\theta = 90°$ which is the limit at the K-shell threshold energy. Here we use (Fischer 1931)

$$J(\theta) = \sin^2 \theta$$

which is non-relativistically correct. Entering this expression into Eq. (6), f can be roughly estimated at the K edge, disregarding multiple scattering.

To summarize, the angular dependent factor f can be calculated at three photon energies and it can be fairly well estimated at the extreme ends of the energy region K edge—5 MeV. It is thus possible to plot $\tau_K\, f$ in a non-arbitrary way.

Something should also be said about the calculations of τ. The theoretical treatment is straightforward but very complicated to carry out rigorously (fast electronic computers are required). The best values given are probably those compiled by G. White 1957. They are taken from graphs obtained from different formulas and from interpolation in the six numerical values of Hulme *et al.* 1935, each theory covering part of the energy range. Three such parts were finally joined smoothly with the aid of experimental results. Unfortunately, the direct comparison between theory and experiment has not yet been possible to a sufficient degree of accuracy (the experiments of Latyshev 1947 and Seemann 1956 form exceptions). Practically all experiments aiming at testing the theory are gamma-ray absorption measurements (Davisson and Evans 1952, Colgate 1952), where the photoelectric absorption cross-section τ_a for the *whole atom* is obtained after subtraction of cross-sections for elastic and inelastic scattering and pair production. Theoretically, cross-section calculations have been carried out for the K shell and, more approximately, for the L- and M-shells. The bridge between theory and experiment, i.e. the ratio τ_a/τ_K, has been lacking till very recently (see above). The $\frac{5}{4}$-rule (i.e. 80 % of the total absorption take place in the K-shell), which is sometimes employed, has limited experimental justification and has served only as a rough estimate (G. White uses theoretical values which are somewhat lower; see above). The difficulties in this field are thus considerable. Eq. (8) shows clearly the intimate connection between ε and τ; the precision in the measurements of absolute internal conversion coefficients would obviously be improved if the photoelectric cross-sections were known theoretically with greater accuracy. An effort in this direction would be of great interest. G. White indicates 5–15 % as an estimate of the accuracy of the presented cross-sections without any closer specification. The only procedure would then seem to be accepting a mean uncertainty of 10 % in the given τ_K-values (see, however, below).

It is obvious that Eq. (8) could as well be used for the experimental determination of τ_K where the ε-value is accurately known. It might be argued that, in view of the relatively large mean error in τ_K and of the great interest that for some time has been devoted to the correct calculation of ε (including finite size effects), such a procedure should be adopted to begin with in order to obtain semi-empirical τ_K:s. There are, however, probably not many cases of definitely known multipolarity mixing ratios and with sufficiently simple decay schemes to permit of a determination of τ_K to an accuracy better than 10 %. It is nevertheless obvious that the application of Eq. (8) gives a new method for the experimental determination of τ_K absolutely and it is probably the only technique which might be expected to give accurate τ_K:s at high quantum energies (above 1 MeV, say) where absorption methods fail completely.

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[1] Throughout the text it is assumed that $\vartheta_0 > 45$–$50°$ which is easily realized in practice.

Another point in favour of the procedure adopted, namely to use Eq. (8) for a determination of ε in the application to the decay of Cs^{137}, is that precise absorption measurements were carried out on uranium (using this very Cs isotope) by Colgate 1952, who claims an accuracy of 0.5 % in the deduced value of τ_a, at 662 keV. Dividing his τ_a by the experimental τ_a/τ_K (see above) a τ_K is obtained which is about 5 % lower than the tabulated value. Colgate also carried out measurements at 412 and 1332 keV and here the corresponding τ_K values turn out to be about 3 % and 15 % low, respectively. Above 1.02 MeV pair production begins and τ_a becomes very small implying that the discrepancy at the high energy should not be overestimated. It is, however, felt that the accuracy in the tabulated τ_K might, as an average, be better than 10 %, perhaps 5–7 %.

Experiments

The activity consisted of 1 mC Cs^{137} in 1-normal nitric acid, and was obtained from the Radiochemical Centre, Amersham. From this solution two radioactive sources were prepared; a strong one on a Pt backing by dropwise evaporation and a weak one by vacuum evaporation (Stockendal and Bergkvist 1957). The sources were circular with a diameter of 6 mm. The weak source was intended for the internal conversion measurements and the strong one for recording photoelectrons from a uranium converter for the determination of the gamma-ray intensity. The necessity for using two sources arose from an estimate of the ratio between the expected conversion line and photoline counting rates (using the *same* source) according to Eq. (8) above. This ratio was found to be of the order of 700 for an $M4$ transition of 662 keV in Ba^{137} with due regard to the intended experimental set-up. Requiring a counting rate of about 200 counts/min on the photoline peak for the sake of statistics the same source will thus give a conversion-line peak counting-rate of the order of 10^5 counts/min which clearly is too much for a GM-counter, if excessive dead time corrections are to be avoided. It was thus decided to prepare two similar sources because it was considered that a determination of the relative strengths could be far more trusted than the operation of a GM-counter at enormous counting rates. The possibility of varying baffle widths in the spectrometer could not be realized because necessary information about the change of the transmission was lacking and, moreover, the reproducibility of the baffle positions is not sufficiently good.

The experiments were performed in a double focusing beta-ray spectrometer of 50 cm mean radius. The 662 keV conversion line from the weak source was recorded and then the strong sample was put in (covered with 1 mm Al to cut out conversion electrons). A circular uranium converter with the radius 7.3 mm and the surface thickness 2.19 mg/cm² U was fixed to the aluminium in a way analogous to that shown in Fig. 1 of the paper by Novakov *et al.* 1958 and then the photoline, produced by external conversion of the 662 keV gamma rays in the U converter, was measured. Five such double runs were made with a resolution of 0.7 %. Fig. 2 gives the result of such an experiment. It should be observed that the resolution is the same for both peaks and that here is a case where the lines can be accurately measured. Because of the low and comparable counting rates the dead time correc-

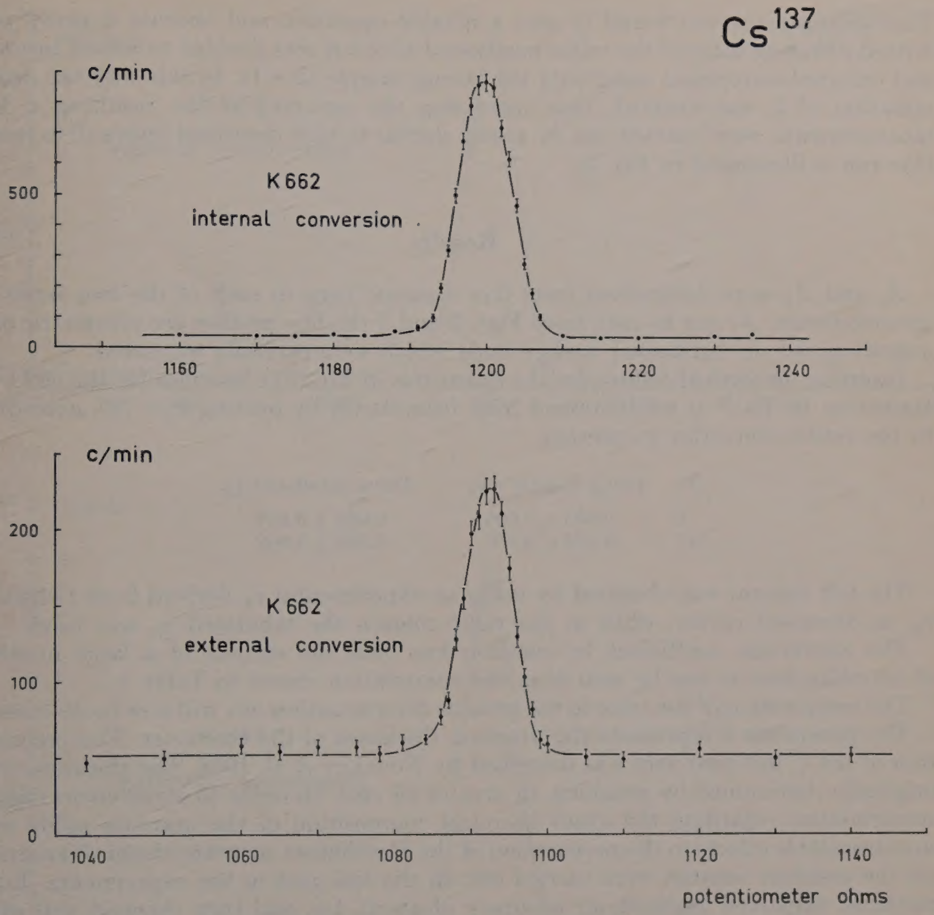

Fig. 2. The 662 keV transition, recorded with a GM-counter, in internal and external conversion. A 2.19 mg/cm² U converter was used in the latter case. $k = 147$.

tion for the GM-counter is negligible. A single GM-counter with a thin mylar foil window was used as detector.

In order to apply Eq. (8) for the calculation of ε the relative source strength k must be accurately known. For this purpose a determination of k was undertaken as a separate experiment using a scintillation counter. The counting rates were measured when the samples—one after another—were put in the same position at various distances from the crystal. Corrections were made for the recovery time of the detecting arrangement, determined in connection with this experiment. The ratio k was also determined with another scintillation counter and with a GM-counter. The results obtained were in good agreement, giving $k = 147 \pm 3$ as a mean value.

Since these experiments were performed a scintillation counter equipment was constructed and put into operation in the double-focusing spectrometer (Stockendal and Hultberg 1958). A plastic scintillator was used, realizing a dead time of 2–3 μs.

This arrangement was found to give a reliable operation and because it easily permitted counting rates of the order mentioned above it was decided to record internal and external conversion using only the strong sample ($k = 1$). In this way the determination of k was avoided, thus increasing the accuracy of the resulting ε. The measurements were carried out in a way similar to that described above (five runs). One run is illustrated in Fig. 3.

Results

A_β and A_γ were determined from five separate runs in each of the two series of measurements. As can be seen from Figs. 2 and 3 the line profiles are symmetric and superimposed on horizontal backgrounds which were carefully measured.

Inserting numerical values for the quantities in Eq. (8) ε becomes for the 662 keV transition in Ba^{137} (f was obtained from formula (6) by putting $\vartheta_0 = 78°$, according to the source-converter geometry):

k	Using Colgate's τ_K	Using tabulated τ_K
1	0.093 ± 0.006	0.098 ± 0.008
147	0.093 ± 0.006	0.098 ± 0.008

The left column was obtained by using an experimental τ_K derived from Colgate's τ_a, as discussed earlier, while in the right column the tabulated τ_K was used.

The conversion coefficient in question has been the subject of a large number of investigations as can be seen from the compilation shown in Table 1.

The composition of the error in the present determination of ε will now be discussed.

The parameter d represents the uranium thickness of the converter. The preparation of the U foil used here was described by Novakov *et al.* 1958. The thickness was originally determined by weighing an area of 63 cm^2. In order to avoid errors due to uncertainties regarding the exact chemical composition of the uranium oxide and uncontrollable effects in the preparation of the U radiators accurate chemical analyses on the uranium content were carried out on the foil used in the experiments. Both methods employed claimed an accuracy of about 1 % and they checked well with each other giving, as a mean value, $d = 2.19 \pm 0.02$.

The quantity b, being calculated from atomic constants, gives no contribution to the total error.

The factor k gives the relative strength of the sources used. In one series it was exactly 1 and in the other it was carefully measured. The error in the latter case should not exceed 2 %.

The uncertainty in f mainly derives from errors in the determination of the integration limits (see Eq. (6)) on the angular distribution curve. The error should be limited to about 5 %.

An uncertainty of 3 % was estimated for A_β/A_γ in each series of 5 runs.

The error in the τ_K as derived from Colgate's experiments is estimated to be at most 2 %. The uncertainty in the theoretical τ_K is taken to be about 6 % (see discussion earlier in this paper).

Added quadratically these errors give the uncertainties entered in the above table for ε.

The method for the determination of absolute ε-values treated in this paper has proved to work very well in the special application to Cs^{137} and also when applied

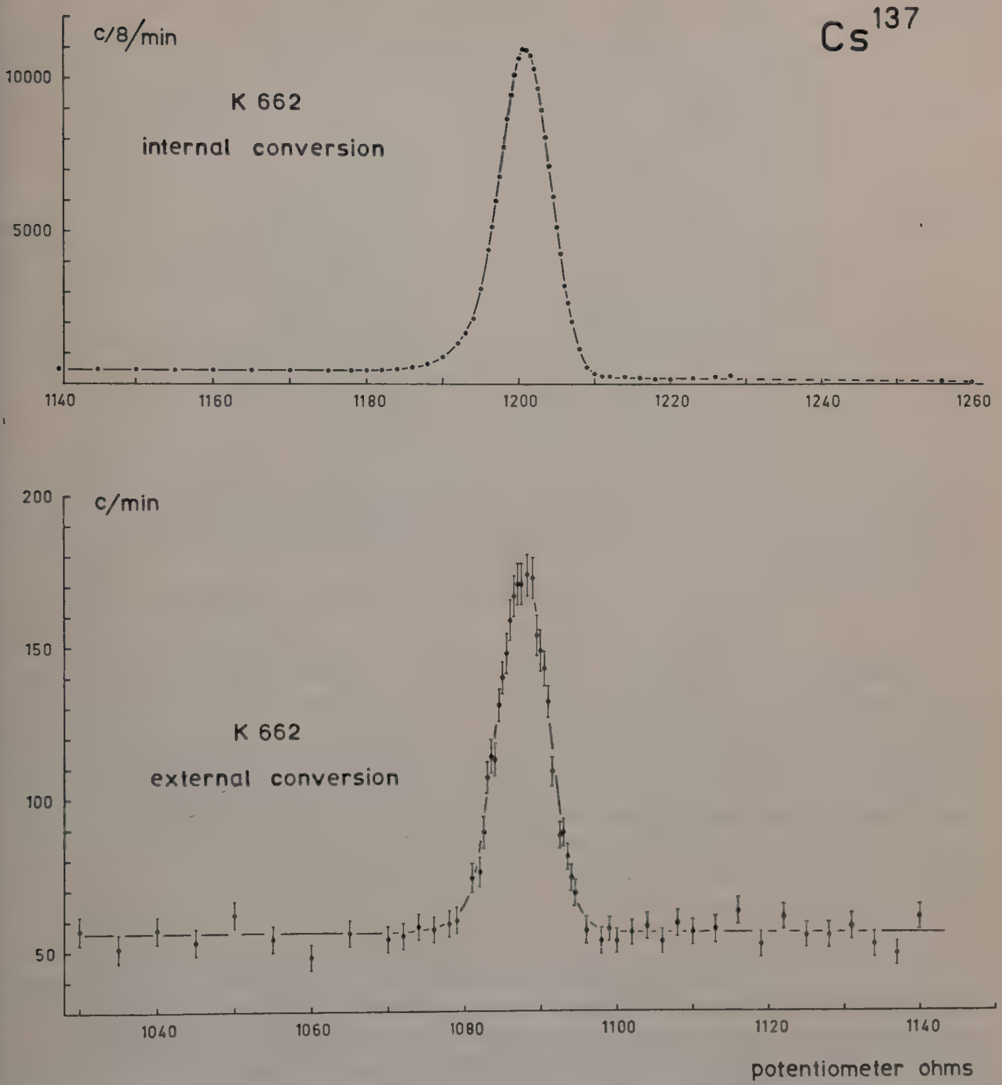

Fig. 3. The 662 keV transition, recorded with a plastic scintillator, in internal and external conversion. A 2.19 mg/cm^2 U converter was used in the latter case. $k = 1$.

to the complex decays of Bi^{205} and Bi^{206} (Stockendal and Hultberg 1959). There are consequently strong reasons to believe in its general usefulness in any beta-spectrometer. Eqs. (6) and (8) have not yet been applied to the case of a ring-focusing helical spectrometer but it should be equally possible if the somewhat more complicated integration over the ring baffle is carried out (cf. Murray 1954, Thomas 1952). Details about the angular distributions will be given later in this journal in order that the factor *f* may be evaluated by anybody.

Table 1. The conversion coefficient of the 662 keV transition in Ba^{137}. The numbers inside parentheses indicate experimental method and refer to page 565.

Experiment	
Mitchell *et al.* 1949 (2)	0.118
Osoba 1949 (2)	0.081
Waggoner 1950, 1951 (2, 4)	0.097 ± 0.005 0.097 ± 0.003[a]
Heath and Bell 1952 (1)	0.095 ± 0.005
Wapstra 1954 (2)	0.092 ± 0.006
Ricci 1957 (2)	0.093 ± 0.018[b]
Katoh *et al.* 1957	0.098
Yoshizawa 1958 (2)	0.0976 ± 0.0055
Present authors (4)	0.093 ± 0.006
Theory	
Sliv and Band 1956	0.092
Rose 1958	0.093

[a] In order to arrive at this value Gray's empirical formula for τ_a (Gray 1931) was used to obtain relative τ_K-values. The error given does, however, *not* include an estimate of the uncertainty in using Gray's formula, nor does it take into account the error due to the neglect of the change of the angular distribution with energy. The error given is thus not relevant for the *true* accuracy of the measurement.

[b] Obtained from $\varepsilon_{tot} = 0.114 \pm 0.022$, as given by Ricci, using $K : L : M$–ratios of Yoshizawa 1958.

In conclusion it should be observed that in cases where the atomic number Z is high (for instance in the important lead region) photoelectric converters might be made of the same material as that of the activity and then the conversion lines and the photolines will appear at identical positions in the momentum scale. This means in turn that it should be possible to measure internal conversion coefficients with good accuracy even at very low energies where the intensity response of the beta-ray spectrometer may not else be relied upon and/or where the effect of a GM-counter window on the counting rate may not be negligible.

SUMMARY

The method for the determination of *absolute* values of internal conversion coefficients by the beta-spectrometric comparison of conversion line and photoline intensities has been studied. The deduction of gamma-ray intensities from measured photolines is treated and it is shown that experimentally determined photoelectric distributions can be used in the theoretical formulae to a good approximation. The instrument used is a flat double-focusing beta-ray spectrometer and general expressions are given for a source–converter assembly of cylindrical symmetry about the spectrometer axis. An application was made to the 662 keV $M4$ transition in Ba^{137} and the conversion coefficient was found to be 0.093 ± 0.006. A 2.19 ± 0.02 mg/cm² uranium converter was used.

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